Plate 5: Surficial Geology and Landforms—Expanded Explanation
City of Alexandria, VA and Vicinity
By Tony Fleming, March 2008

Introduction

The Alexandria landscape consists of what could be called an incompletely dissected plateau, ringed on three sides by deeply entrenched stream valleys. The landscape is chiefly the product of fluvial action by the Potomac River, which included episodes of both deposition and erosion, beginning in the late Tertiary and continuing until the present. Incision of the landscape occurred in discrete episodes, punctuated by stable periods when the river deposited extensive terraces at each level. With each new pulse of downcutting, the river would leave behind a terrace marking the surface upon which it had recently flowed; forces of erosion would immediately begin acting on the terrace, triggering renewed transport of sediment from higher parts of the landscape down onto the newly steepened slopes. Sediment thus eroded would be recycled, or reworked, into the next terrace and into various slope deposits flanking it, in a cycle of geological cannibalism. This cycle may have repeated itself as many as 10 or 12 times since the late Tertiary, based on the number and positions of terrace remnants visible in the modern landscape. The most dramatic downcutting has taken place relatively recently, as the Potomac River and its tributaries continue to respond to major sea-level lowering during the Ice Age. All of the major drainages, and most of the smaller ravines in and adjacent to the city, owe their present forms to this period. The Pleistocene climate is also responsible for the origin and current location of the Fall Zone, which separates the crystalline rocks of the Piedmont to the west from the softer sediments of the Coastal Plain to the east, and is exemplified by Holmes Run gorge. The result of all this activity is a landscape underlain by a complex mosaic of terraces, slope deposits, and modern alluvium that mantles the underlying bedrock and Coastal Plain sediments. Plate 5 shows the distribution of these deposits, and the kinds of landforms they occur within.

Definition and Significance of Surficial Deposits

Plate 5 is a map of the surficial geology of the city. As the name implies, “surficial” refers to the materials that comprise and immediately underlie the modern land surface. By virtue of their proximity to the surface, these are the materials initially encountered when humans interact with the soil-geologic environment, whether it be shallow construction, gardening, managing property, or simply enjoying nature and the out-of-doors.

The map units encompass a wide range of geologic materials. In the Holmes Run gorge area, several types of ancient crystalline bedrock of the Piedmont (and soils developed on it) crop out or are extremely close to the surface. In other places, the early Cretaceous Potomac Formation is present at the surface, most commonly in ravines and on other moderate to steep slopes where there is little surficial sediment accumulating. As detailed in plate 4, the Potomac Formation is up to 400 feet thick and consists of 6 major mappable units within the city, and several minor ones, each representing a somewhat different sedimentary environment characterized by a specific association of lithologies. But over large parts of the map area, the bedrock and Potomac Formation are concealed beneath a veneer of much younger and thinner deposits, which consist chiefly of alluvial terraces and slope deposits of widely varying ages, compositions, and position in the landscape. Many of the slope deposits are comparatively thin and transient (in geological terms), but they are nevertheless sufficiently thick at many places to dominate or have a major impact on the soil profile, and are thus of great importance to human and ecological affairs. Slope and stream deposits of one sort or another are present to at least a few inches depth on nearly every hillside and in every ravine in the city. Hence, the decision of where to show these units on the map (as opposed to highlighting the underlying bedrock or Potomac Formation units) was not always simple, but ultimately was based on the foregoing concept, which bears repeating: *slope deposits, such as colluvium, as well as alluvial deposits, are shown where they are generally of sufficient thickness to dominate or have a major impact on the soil profile*. In practical terms, this means that these deposits are more likely than not to affect the consistency, texture, profile development, strength and stability, and ecological properties of the soil within the areas where they are mapped, and thus have a major impact on the environmental function of the landscape. They are also the deposits people will actually see when they look at the soil surface in these areas.

Previous Studies

For the most part, the surficial deposits have received relatively little attention in past studies, and the sources of information bearing on their geology are the same as for the bedrock and Potomac Formation. The preliminary geologic map of Fairfax County (Drake and others, 1979) shows several areas of colluvium overlying the Potomac Formation in parts of the present map area, but these deposits are not differentiated by age or origin. The geologic map of the Annandale Quadrangle (Drake and Froelich, 1986) shows a few small areas of colluvium, lag gravel, and landslide deposits, none of which lie within the city limits. It also shows extensive areas of terraces bordering modern streams, but all of these are grouped into one unit without respect to age or position in the landscape. The surficial deposits shown on these maps is, to some extent, based on work done by Langer (1978) and Force (1975), which was incorporated into the "Simplified surficial materials map of the Coastal Plain" of Fairfax County presented in Froelich (1985). The geologic map of the Washington West quadrangle (Fleming and others, 1994) distinguishes areas of Pleistocene and Tertiary colluvium, and breaks out the terraces bordering the Potomac River into five Pleistocene units based on their degree of weathering, position in the landscape, and inferred age. Likewise, the Annandale, Falls Church, and Washington West geological maps also contain fairly detailed descriptions of the lithologies and weathering features associated with each of the several upland river terraces, some of which are presumably equivalent to the terraces that cap the Alexandria uplands.

The upland river terraces have probably received the most attention, in no small part because their ages are a subject of considerable controversy and speculation. Early workers (c.f., Darton, 1947, and Johnston, 1964, for useful historical discussions) tended to regard most, if not all of the terraces that extend into Alexandria as being of Pleistocene age, with some of the higher, outlying upland gravels in Fairfax County (e.g., at Tysons Corner) potentially being of late Tertiary age. These two broad subdivisions were referred to as the "Brandywine" and Bryn mar" gravels, respectively. In more recent work, all of the upland terraces in the city (or their equivalents in surrounding jurisdictions) have been interpreted to be late Tertiary, based in part on presumed correlations with formations of the same age further east in the Coastal Plain (c.f., McCartan, 1989, and Fleming and others, 1994); a fossil cypress log recovered from the highest terrace at Tysons Corner (Drake and Froelich, 1997) points toward a late Miocene age for that unit, but has little bearing on the ages of the terraces in Alexandria, which are much lower in elevation and clearly younger. Nevertheless, all of the upland terraces above about 130 feet in elevation are assigned to the late Tertiary in all of the published geological quadrangle maps produced by the USGS during the last 20 years or so. This assignment spawned a cumbersome and simplistic scheme of using alpha-numeric designations to identify each terrace, for example T1, T2, T3, etc. This scheme has not been applied consistently, leading to considerable confusion. In Fairfax County, for example, the highest terrace (at Tysons Corner) is referred to as "T1" (c.f., Drake and Froelich, 1997), while the lowest of the upland terraces is called "T5" (c.f., Drake and others, 1979). But in the District of Columbia and Maryland, the exact opposite is true: the lowest of the upland terraces is referred to as "T1", with higher numbers assigned to progressively higher terraces (c.f., Fleming and others, 1994).

The present study does not agree with the concept of late Tertiary ages for all of these upland terraces—nor with using the alphanumeric scheme to connote relative ages—and instead recognizes that the ages of the terraces are highly speculative because reasonable arguments can be made for either a late Tertiary or an early to middle Pleistocene age, or both. Age determinations for the three lowest terraces (Dowden, Chinquapin Village, and Beverley Hills terraces of this study, presumably equivalent to T3, T4, and T5 of Drake and others, 1979) are especially problematic. If all these terraces are late Tertiary, it begs the question "Whither the Pleistocene"?

Evidence from ice cores and the stratigraphic record from large buried bedrock valleys and elsewhere in the glaciated Midwest (c.f., Bleuer, 1991; Hallberg, 1986) suggests that there were numerous periods of glaciation, beginning in the early Pleistocene, when sea level would have been depressed, triggering downcutting by the Potomac River and leaving a terrace to record each event. Yet the next major terrace below the lowest of the upland terraces (surface elevation 130-150') is the Old Town terrace, which stands some 30-50 feet above sea level and is widely considered to be Sangamon age—relatively late in the game. Although there are scattered small terrace remnants plastered onto the valley walls between these two larger terraces, it seems inconceivable that the whole record of the Pleistocene prior to the Sangamon Interglacial—with its many major glaciations—is represented by only a few fragmental patches of gravel. One might reasonably ask why there aren't major terraces associated with, say, the Illinoian Stage, which far surpassed the Wisconsin Stage in terms of sheer ice volume and coverage, or any number of pre-Illinoian stages. The answer may be that they have been stripped away by erosion—or not. The oldest of the Pleistocene terraces (unit Qt5) shown on the Washington West quadrangle is inferred to be about 450,000 years old (Fleming and others, 1994), which still leaves most of the pre-Illinoian stages of the Pleistocene unaccounted for by terraces. Interestingly, parts of the Qt5 terrace (125 feet) approach the elevation (130 feet) of the lowest of the supposed late Tertiary terraces in northern Virginia. Needless to say, the answer to these questions, and the ages of the terraces, is likely to remain controversial and speculative unless and until some piece of definitive evidence turns up, such as the relevant index fossil or a new method of dating the ages of the sediment in the terraces.

Data Sources and Methods

How the Map Was Made: The surficial geology map was made primarily from direct field observations, coupled with analysis of landforms using topographic maps and the city's orthophoto coverage. All of the major terrace surfaces, slopes, ravines, and stream valleys in the city were examined, usually in multiple places, in order to determine the kinds of sediments typically present in each, along with the predominant hydrologic aspects of each landscape. The presence of specialized vegetation communities was also diagnostic of certain geologic conditions; for example, acidic gravel forests are very useful for indicating thick accumulations of colluvium on the slopes below the upland terraces. The locations of key exposures and features are noted on the map of data points (plate 1), and the major observations are also recorded in the database of Alexandria exposures accompanying this study. In addition, many small excavations were either observed directly during the course of fieldwork, or the tailings from previous grading and excavation were present in sufficient quantity at enough places in the landscape to provide a good sense of the underlying material. These observations were supplemented by subsurface data from various wells and geotechnical borings, some of which were useful for gauging the thickness and other properties of surficial materials, as well as the nature of the formations underlying the landforms at depth (e.g., Potomac Formation, bedrock).

Limitations: The biggest challenge for interpreting the surficial geology is the widespread disturbance of the landscape resulting from myriad urban activities. Emplacements of fill are ubiquitous in most parts of the city, and gravel of one kind or another is the most common type of fill material. Such gravelly fill can look misleadingly like native material, especially colluvium, unless the fill contains diagnostic anthropogenic materials (e.g., organic debris, cinders, demolition debris, etc). In such cases, it was not always possible to observe the soil profile for horizonation and other pedogenic and geologic features, which is the most reliable way to determine whether material is native or artificial. Fortunately, the surroundings of most of these places gave a fairly reliable idea as to whether fill was likely to be present. Beyond that, most major landforms in the city contain at least a modicum of undisturbed ground, some of it in native vegetation, which was usually sufficient to give a good sense of the geology.

Closely related to filling is the removal of parts of landforms, or even entire landforms, to make way for buildings and infrastructure. Large parts of the landscape along Shirley Highway, for example, have been completely rearranged. The same is true of almost any large-scale development. This can be both good or bad for geology. Sometimes this work creates new exposures, and at other times, it can totally eliminate key evidence for certain landforms or sediments.

A final challenge, as alluded to earlier, involved the mapping process itself, specifically how extensively to show surficial deposits on hillsides and in ravines, relative to bedrock and the Potomac Formation. In many locations, the surface of a given hillside will consist of some of both; on moderately steep hillsides developed on Potomac Group clays, for example, it is very common to find fairly thick colluvium in concave places, while the clay crops out on steep, convex parts of the hillside. Such variation frequently occurs at a scale finer than what can be easily shown at the present map scale. For the most part, the issue of variation in thickness of colluvium and other surficial materials, and the presence of multiple kinds of substrates within a map unit, are handled in the explanation of the map unit. And, as mentioned before, the impact on the soil profile is the guiding principle used to decide where and how extensively to map a specific surficial material in a particular area. That said, the map is a bit of a compromise, striking a balance between the need to show as wide a variety of surficial units as possible, in the places they characteristically occupy, while also providing a clear indication of the distributions of the underlying bedrock and Coastal Plain units.

Surficial Geology

Late Tertiary-Recent Geologic Conditions: All of the surficial deposits are draped over an east- to southeast-sloping erosion surface on the Potomac Formation and, to a lesser extent, on the bedrock in the vicinity of Holmes Run Gorge. By and large, the great mass of the Potomac Formation accounts for the large amount of topographic relief that characterizes the city; although various surficial deposits dominate the landscape and soil surface at most places in the city, the Potomac Formation is never far below, and commonly crops out on steep slopes and in ravines. The Old Town terrace is the only place where the Potomac Formation is deeply buried and generally not a factor in the landscape.

This erosion surface on the strata underlying the surficial deposits is a complex feature that has been variably truncated and eroded into a series of step-like benches at different times in the geologic past by the Potomac River and its tributaries. The complicated geomorphic history of this feature is reflected by the great disparity in ages between the materials above (late Tertiary and younger) and below (early Cretaceous), which results in a pronounced unconformity of some 100 million years or more across the erosion surface. During this time, the evidence suggests that the landscape was progressively tilted to the east, causing much of the Potomac Formation that originally was present (possibly thousands of feet) to be stripped off by erosion, leaving a relatively smooth, eastward-sloping landscape. At some point in the late Tertiary, the Potomac River (or a precursor stream) began meandering across this surface, producing a broad, alluvial plain upon which a sheet of coarse gravel was deposited. A major component of the gravel came from points west of the modern Blue Ridge Mountains, because it consists of quartzites containing *Skolithos* burrows—a distinctive feature of the early Cambrian Antietam Sandstone of the western Blue Ridge—as well as Paleozoic sandstones that crop out only in the mountains even further west. This suggests that the river that produced the “gravel plains” of the uplands drained a sizable watershed, comparable or possibly larger than the modern Potomac, a conclusion confirmed by recent studies showing that zircons (a common heavy mineral in sands) began coming from source rocks west of the Blue Ridge in Miocene time (c.f., Naeser and others, 2004; Southworth and others, 2006). Cobbles, pebbles, and finer particles derived by weathering of these source rocks are a prominent component of the surficial deposits in Alexandria.

Geologists do not know exactly when this alluvial history began. The oldest such deposits known to the area occur at an elevation of over 500 feet at Tyson's Corner, and are potentially some 12-15 million years old; it is entirely possible that rivers occupied this landscape much earlier, but the evidence for them has been stripped by erosion. But the fact that the late Tertiary Potomac drainage is not thought to have breached the Blue Ridge until the Miocene implies that the dominant lithologies comprising the surficial deposits in Alexandria were not transported into the city until some time after that, which means that the surficial deposits depicted on plate 5 must also not have begun accumulating earlier than that. In fact, much of the area lay along the margin of a shallow sea at several times during the Tertiary, the most recent of which also occurred in the Miocene, some 12-17 m.a., and is represented by thin, discontinuous deposits of pebbly, quartzose beach sand and diatomaceous earth of the Calvert Formation. No convincing evidence of the Calvert Formation was found in Alexandria during this study (though the Shooter's Hill gravel of the Potomac Formation is suggestive), but erosional outliers are well documented below some of the high-elevation gravel caps in nearby places, such as the Tenleytown area of the District of Columbia.

Given the possible presence of a shallow marine environment in the map area in the Miocene, it seems clear that the river that deposited the upland gravel deposits did not begin flowing over this area until the sea withdrew. But once that finally happened, the stage was set for a protracted history characterized by repetitive cycles of alluviation followed by stream incision that continued more or less unabated to the present time. During stable periods of landscape equilibrium, the river would meander over a relatively low-relief alluvial plain, depositing a moderately thick blanket of gravel, sands, and silts. Eventually, the equilibrium would be disrupted, either by tectonic uplift and eastward tilting of the landscape, or by a drop in sea level, causing the river to abandon the alluvial plain and incise a new valley until it again attained a gradient in equilibrium with sea level, and a new alluvial plain formed. In this way, the whole series of river terraces so prominent in the Alexandria landscape were formed, each separated from the ones above and below by a river-cut escarpment. With each new episode of downcutting, the landscape would be thrown into disequilibrium, causing a tremendous amount of sediment to be transported downslope toward the new river level, either by streams or by slope processes. Despite millions of years of erosion, the effects of this process can still be seen in the city today, in the form of ancient alluvial terraces and colluvial deposits, which become progressively younger in a descending, step-like fashion between the highest elevations at the Episcopal Seminary, and the lowest floodplains along the master streams.

One of the most striking results of this process is the obvious recycling, or cannibalization, of earlier deposits by younger ones. The upland terraces and slope deposits in the city are remarkably similar in appearance. The large clasts are dominated by Antietam quartzite from the Blue Ridge, Paleozoic sandstones from the Valley and

Ridge, and vein quartz from the Piedmont, regardless of age or position in the landscape. Only the youngest stream terraces and alluvium, close to the active channels of the large master streams, show appreciable quantities of local rock types, which suggests that the early Paleozoic metamorphic and igneous bedrock now exposed in Holmes, Backlick, and Four Mile Runs was not exhumed until fairly recently, perhaps only during the late Pleistocene or early Holocene. The older deposits appear to be derived largely from sediment that was reworked from higher in the landscape: as the river embarked on each new cycle of downcutting, sediment would be eroded from the terrace it had just abandoned, eventually being incorporated into the next terrace, and into the colluvial deposits that covered the intervening slopes. Evidence of this process is frozen into the landscape in the form of colluvial fans that trail down the escarpments between all of the terraces, starting with the highest ones at Episcopal Seminary and Dowden terrace, and continuing downslope to the most recent alluvium in very young ravines.

The repetitive and cannibalistic nature of the alluviation-erosion-sediment transport cycle has left a complicated and incomplete geologic record composed of a patchwork of surficial deposits of widely varying ages and origins. Interpretation of the precise history of these deposits is rendered highly problematical by their great similarity to one another. Indeed, with few exceptions, it is often difficult to distinguish late Tertiary slope deposits from modern colluvium on the basis of physical appearance alone. Instead, it is necessary to base such distinctions primarily on position in the landscape and relationships to individual terrace surfaces and other landforms. This is the basis for the map units shown on plate 5. In some cases, a useful distinction can be drawn from the intensity of soil development: very old colluvium typically exhibits a strong weathering profile comparable to that observed in the highest river terraces—that is, assuming the colluvium has not continued to move appreciably down the hillside since then. These old deposits commonly exhibit a type of soil profile known as an ultisol, in which all, or nearly all, of the soluble minerals have been thoroughly leached from the profile to considerable depth, and all but the most resistant, siliceous clasts have been weathered into crumbling masses of sand and clay. Ultisols typically exhibit bright reddish-orange soil colors and a prominent, thick "argillic" B horizon characterized by heavy clay accumulation. Young deposits, on the other hand, exhibit much less well-developed weathering profiles, and seldom have well-developed bright colors or argillic horizons. But even soil development is not an infallible method for distinguishing the age of these deposits, on account of the partial erosion and recycling of older deposits—and the soils developed on them—into younger ones. A high-quality exposure of the soil profile is typically required to make a clear distinction.

The forces that led to repeated episodes of stream incision in the late Tertiary are not well defined, as there are no known glaciations or other events during that time that would have caused major changes in global sea level. A stronger possibility appears to be compressional tectonics, which clearly has operated along the east coast for the last 50-100 m.a., and which appears to have progressively tilted the entire regional landscape from west to east. Such tectonic activity may not have acted uniformly over long periods, but may have instead occurred spasmodically, perhaps acting on the landscape via uplift along such well-documented local Tertiary faults as the Rock Creek Shear Zone

(Fleming and Drake, 1998) and the Stafford Fault Zone (Mixon and Newell, 1977). Motion along both of these fault zones exhibits a clear west-side-up sense, indicating that displacement would have steepened existing the gradients of existing east-flowing rivers and streams, thereby enhancing rates of stream incision.

On the other hand, there is little doubt about the cause of stream incision after the Tertiary. Multiple glaciations during the Pleistocene triggered repeated sea-level drops of as much as 300 feet or more as massive continental ice sheets locked up large volumes of the world's water in ice for periods ranging up to several tens of thousands of years. Stratigraphic evidence from the glaciated Midwest indicates there were as many as 6 or 8 of these glacial stages in North America during the Pleistocene, separated by prolonged warm periods when the ice sheets melted and weathering profiles formed in the most recently deposited glacial sediments. The ice core record suggests there may have been even more stages. The divergence between the Pleistocene—with its clear cause for multiple episodes of stream incision and resulting terrace formation—and the late Tertiary, where evidence for such a cause is obscure, prompts yet another reason for calling into question the presumed late Tertiary ages assigned to all of the upland terraces. In Alexandria, which has one of the best-preserved sequences of terraces anywhere in the region, there is little evidence of extensive terrace formation between the Beverley Hills terrace—the lowest of the supposed late Tertiary upland terraces—and the late Pleistocene Old Town terrace. Scattered, small patches of gravel plastered along the valley walls of Cameron and Holmes Runs are the only suggestion of terraces in this part of the landscape; these deposits are isolated and scarcely define any sort of major terrace strath. Given the record of dramatic and repeated sea-level changes during the entire one million years of the Pleistocene, it is difficult to fathom why there should be such a scant record of corresponding terraces—random chance suggests that at least one or two such terraces might have survived the ravages of erosion—unless some of the upland terraces are actually Pleistocene age. For this reason, the three lowest upland terraces in the city—the Beverley Hills, Chinquapin Village, and Dowden terraces—are considered to potentially be *either* Tertiary or Pleistocene in age, though only the Beverley Hills terrace is so designated on plate 5 by use of "QT" in its label. As was noted previously, current evidence offers no clear answer to this conundrum.

Tertiary-Early Pleistocene Terrace Deposits: Four upland terraces were recognized in the city during this study. Although they are variously dissected, all are relatively sizable and readily distinguished from one another and from lower terraces on the basis of their consistent surface elevations, surface morphology, geographic distributions, and other features. For convenience in mapping and discussion, they are given informal local names based on a conspicuous feature or place within their distribution. From highest to lowest, they are: 1) **Seminary terrace**, with a typical surface elevation between 265 and 280 feet; 2) **Dowden terrace**, with a surface elevation that is mostly between 240 and 250 feet; 3) **Chinquapin Village terrace**, typically at 180-200 feet; and 4) **Beverley Hills terrace**, with an average elevation of 145-150 feet.

On the preliminary geologic map of Fairfax County (Drake and others, 1979), Seminary terrace is not distinguished from Dowden terrace (both are called "T3" on that map), but there is strong evidence in the city that they are distinct terraces. The boundary between them is particular prominent along Seminary Road between Pegram and Howard Streets, where it forms a sharp, colluvium-covered escarpment about 30 feet high, across which the bases of the two terraces appear to be offset by anywhere between a few feet and 25 feet. While it is possible that the scarp might be the result of a fault, this seems unlikely because there is no other line of evidence indicating a fault at this location, unlike the faults mapped elsewhere. The Seminary terrace also appears to be capped by a substantial thickness (up to 15 feet) of fine-grained sediment, typically heavy fine-sandy silt, which creates a widespread, swampy landscape over large areas of the Episcopal Seminary. Clayey silt also caps portions of the Dowden terrace, but it lacks the abundant sand evident in the Seminary silt cap, and is typically less than 10 feet thick. No appreciable difference in weathering was observed between the two terraces, but this may be a function of substantial differences in parent materials: large parts of the Seminary terrace are characterized by poorly-drained, fine-grained, gleyed, hydric inceptisols with a prominent claypan, whereas brightly-colored ultisols on gravel are more typical of the Dowden terrace.

Except for any fine-grained capping sediment, all four terraces are composed predominantly of gravel in a brightly oxidized matrix of well-weathered loam. The loam is derived from chemical breakdown of feldspars, rock fragments, and other non-resistant clasts. Matrix colors tend to be brightest (strong yellow-red) in well-drained parts of the two highest terraces (Seminary and Dowden), indicating a longer period of weathering than the lower terraces, which are typified by brownish-yellow to yellow-orange matrix colors. Soil profiles with prominent fragipans were observed on the gravel in flat parts of all four terraces.

The gravel consists almost entirely of resistant, siliceous types, chiefly vein quartz, quartzite, and quartz sandstone. Clasts are commonly moderately to well rounded, polished, and stained with iron oxides. Pitting of the surfaces of some pebbles was observed in exposures of the Dowden terrace, suggesting intense weathering. The gravel is mostly very poorly organized, typically exhibiting a crude stratification or imbrication of clasts. The majority of clasts are in the coarse gravel fraction; however, cobbles are common, and boulders up to several feet long were observed in all four terraces or in colluvium and alluvium derived from them. The largest boulders observed during this project are at least 6 feet long and were found along Timber Branch at the base of Ivy Hill Cemetery. The boulders are within an alluvial terrace and were apparently derived from the Beverley Hills terrace on the hillside above. Boulders in the 3-4-foot range are fairly common and can be seen along the edges of most of the terraces. The coarseness of the gravel indicates that most of it is bed load dragged along the bottoms of channels during floods and deposited in bars. Much of it was probably open-type framework cobble gravel in which finer pebbles and sand transported by smaller floods filled in around the larger clasts. Occasional beds and short sections of sand are reported to be interbedded with the gravel in a number of geotechnical borings. Relatively thin layers of trough cross-bedded coarse pebbly sand of this type was observed in several excavations.

Distinct from the gravels are a series of fine-grained sediments found in association with all of the terraces. This material is typically clayey silt, silt loam, and/or loam in composition, and in nearly all cases, it occurs on the surfaces of the terraces, sometimes over wide areas. Some of these sediments exhibit very fine graded beds and wavy laminations, but mostly it has a massive appearance. It is almost invariably devoid of gravel. The fine-grained sediment on each terrace appears to have been deposited at the same time or shortly after the gravel that makes up the bulk of the terrace, mainly as alluvial overbank sediment, swamp deposits, and possibly in small swales and oxbows. Fine-grained sediment is particularly abundant on the surfaces of the Seminary and Chinquapin Village terraces. Fine-sandy silt, typically with a well-developed fragipan or clay pan, caps virtually all of the highest part of the Seminary terrace, which also is the highest place in the city; the associated landscape is very poorly drained and characterized by micro-hummocky topography and distinct swales and subtle ridges—elements that could be inherited from an original floodplain. This landscape is essentially undissected and probably represents an original depositional surface, presumably a wide, swampy floodplain subject to occasional overbank flooding. The modern landscape retains abundant swamp vegetation and hydrology, and was probably an extensive, precipitation-fed upland swamp prior to settlement.

In contrast, fine-grained sediments on the surface of the Chinquapin Village terrace occur in distinct belts near the original inner margin of the terrace, paralleling the base of the river-cut Fort Ward escarpment that separates the terrace from the adjacent Seminary terrace. A belt of heavy, clayey silt lies adjacent to the scarp and probably represents a backwater swamp or floodplain terrace. The silt is more than ten feet thick at places and is commonly thicker than the underlying gravel close to the edge of the terrace. Relict swamp hydrology and vegetation is widespread on the silt, being well displayed in parts of Chinquapin Village, Chapel Hill, and along the eastern edge of Episcopal Seminary. A second belt, composed mostly of loam and very sandy silt, lies on the inboard side of the heavy silt. It is well exposed in South Fairlington and Oakcrest, where it typically consists of medium orange brown, massive, well-drained loam. The original deposit is inferred to have been silty, feldspathic sand, which has since weathered into loam. Plane laminations were observed in two shallow utility trenches in South Fairlington. The loam was probably deposited in a more proximal part of the same floodplain where the heavy silt was.

Smaller areas of clayey silt and similar fine-grained sediment cap parts of the Dowden and Beverley Hills terraces. The surfaces of both of these terraces are significantly more dissected and deflated than the other two, hence it is thought that the present erosion surface of both terraces mostly lies below the original depositional surface. Known areas of fine-grained sediments occur on the highest, flattest, and thus presumably least eroded sections. The best example is in the vicinity of Dowden Terrace, which is characterized by a gently undulating, somewhat poorly drained landscape that lacks any visible gravel on the surface and exhibits abundant swamp vegetation in a few low swales. An excavation in this landscape exposed several feet of very heavy clayey silt, with nary a pebble to be seen. The soil profile exhibited strong mottling and a heavy clay pan, indicating a shallow seasonal water table. Almost all of the Beverley Hills terrace is strongly dissected, and most of its surface is thought to be moderately stripped by erosion. Fine-grained material appears to be present only in small isolated patches, a good example being the clayey silt that underlies the upland along Janneys Lane, immediately east of Taylor Run. Although engineering borings on this terrace are sparse, the few that do exist suggest that some of the fine-grained sediment may be interbedded with the gravel. This is also true to an extent on the Chinquapin Village terrace.

As noted previously, the ages of these terraces could theoretically range from late Miocene to early, or even mid Pleistocene. The intensity of weathering is compatible with any of these ages, and compares favorably to some of the paleosols observed in early and middle Pleistocene deposits of the mid continent. For purposes of this map, the three highest terraces—the Seminary, Dowden, and Chinquapin Village—are labeled as Tertiary, whereas the lowest terrace—the Beverley Hills—is labeled as either Quaternary or Tertiary. It should be understood that the age assignments of all of these terraces are speculative. All that can be definitively said is that all of the upland terraces post-date the Miocene Calvert Formation.

Tertiary-Early Pleistocene Escarpments: Three relict, river-cut escarpments are preserved in parts of the city and separate portions of the upland terraces. These remnants represent short segments of much longer escarpments that were cut when the river migrated to successively lower levels; in essence, they are relict valley walls. Most of the original escarpments have been eroded away, leaving only a few remaining fragments, most of which are somewhat dissected by the heads of modern ravines, but still retain their basic form. The escarpments are held up by fine- and medium-grained sediments of the Potomac Formation, chiefly the Arell clay and Lincolnia silty clay in the central and western part of the uplands, and the Chinquapin Hollow fine sandy clay in the northeast. They typically form gentle to moderately steep slopes with sharply convex summits and concave toes. Old gravelly colluvium eroded off the adjacent terrace typically mantles the surface of each scarp, and ranges from a few inches to a couple of feet thick, exceptionally attaining thicknesses of several feet adjacent to ravines and hollows. Strongly developed ultisols are typical, with the upper part of the soil profile having formed in gravelly colluvium and the lower part in Potomac sediments. There is little evidence of recent movement of the colluvium on most of these scarps, except close to a few active, deep ravines. Each scarp is roughly the same age as the terrace at its base, that is, they could range from late Tertiary to early Pleistocene in age. As with the upland terraces, each escarpment is given an informal local name for reference purposes.

The **Varsity Park escarpment** is the oldest of the three upland scarps, forming a short, mostly gentle slope that trends north-south across Seminary Road and separates Seminary and Dowden terraces between Braddock Road and Varsity Park. Maximum relief is about 30-35 feet. The scarp is held up by the Arell clay, which is mantled at most places by moderately thick colluvial gravel that creates a fairly dry growing environment. No evidence of landslides was observed on the scarp, which appears fairly stable. The scarp is well displayed on Seminary Road, just east of Pegram Street. The north and south ends of the scarp are truncated by the head of Lucky Run and Holmes Run Valley, respectively.

The north end of the Varsity Park scarp very nearly intersects the much larger, northwest-trending **Fort Ward escarpment**, which consists of two sections, respectively, north and south of Shirley Highway. The **southern section** separates Seminary terrace from the much lower Chinquapin Village terrace. This is the longest and tallest upland scarp segment remaining in the city. The massive southern end has some 60-75 feet of topographic relief and completely wraps around the southeastern end of the Episcopal Seminary, before bending northwest and extending through Fort Ward Park, where the relief is slightly less. The nature of the scarp landscape is well displayed on the slopes below Fort Ward, where a few inches to a few feet of gravelly and cobbly colluvium can be seen to overlie the Arell clay; all of these materials are deeply weathered and exhibit bright orange-brown soil colors at this location. Relict vegetation suggests that this may have been a somewhat dry environment prior to settlement. Most of the southern section of the scarp exhibits moderate or gentle slopes and appears relatively stable; however, the steepest parts of this scarp may be prone to small landslides and rotational slumps due to the inherently unstable nature of the underlying clay. The southern end of the scarp appears to be offset across the Fort Williams fault. The other end of the scarp is abruptly truncated above Shirley Highway by the head of Lucky Run. The map pattern suggests that the Fort Ward escarpment truncated the Varsity Park escarpment in this location prior to late Pleistocene incision of Lucky Run.

The **northern section** of the Fort Ward escarpment is very different and appears as several isolated, erosional remnants at various places in the deeply dissected upper Lucky Run drainage between Beauregard Street and Route 7. These remnants form moderately steep slopes that separate the Dowden and Chinquapin Village terraces. They typically exhibit about 40-50 feet of total relief, and are usually surrounded by steep slopes flanking the deeply entrenched ravines in the headwaters of Lucky Run. The surface is covered by a thin veneer of colluvial pebbles derived from the adjacent Dowden terrace, and overlies Lincolnia silty clay at shallow depth. Most of the soil profile is developed in the silty clay, and because of the relatively steep slopes on and surrounding this escarpment, it appears to be less stable than the others, with several potential prehistoric landslide scars being noted on the steepest portions.

The **Jefferson Park escarpment** is the lowest and youngest of the upland scarps. It separates the Chinquapin Village and Beverley Hills terraces in the northeast part of the uplands, where it is developed on mixed sandy, silty, and clayey sediments of the Chinquapin Hollow member of the Potomac Formation. Typical relief is about 40 feet at most places. Slopes are gentle to moderately steep, with abundant colluvial gravel. As seen in several small excavations, the colluvium was generally less than 2 feet thick, and occurred within the top of a brownish-yellow ultisol that extended down into the underlying Potomac Formation. These slopes appear to be relatively stable, with no observed landslide scars.

The escarpment is a continuous feature in the vicinity of Monticello and Jefferson Parks, where its markedly curved course marks the presence of a sharp bend in the river that cut the scarp. A prominent reentrant occurs on the north side of Timber Branch, where a high-level stream terrace on the valley wall appears to be graded to the Beverley Hills terrace. This relation suggests that Timber Branch existed at the time the escarpment was cut, and that the reentrant marks the confluence of the ancestral Timber Branch with the river when it occupied the Beverley Hills terrace. South of Timber Branch, the escarpment becomes fragmented by the strong dissection associated with both Timber Branch and Taylor Run. Moreover, relations south of Taylor Run are further complicated by faulting, which appears to have interrupted the continuity of the escarpment, and by fluvial erosion. A series of narrow, intermediate-level terrace remnants and intervening colluvial slopes in Chinquapin Park and areas just to the southwest are probably a combination of down-faulted extensions of the Chinquapin Village terrace and benches cut by the river as it was downcutting to the Beverley Hills terrace. Unfortunately, strong late Pleistocene incision of Timber Branch and Taylor Run has severely attenuated these remnants and destroyed much of the evidence that might have helped interpret the relationship between tectonics and fluvial terrace formation. Small remnants of this escarpment south of Taylor Run overlie Arell clay; some of these are being actively undermined by strong incision of the adjacent valley, resulting in a heightened potential for slope failures along their margins.

Tertiary-Recent Slope Deposits and Associations: Several types of slope deposits are widespread in the map area. The most common consist of gravelly and cobbly colluvium in a fine-grained matrix, which occurs in a variety of landforms and positions in the landscape. Colluvium is defined as sediment that moves down hillsides under the influence of frost heaving and gravity: when the ground freezes, individual particles are lifted ever so slightly outward in a direction perpendicular to the slope; when the ground thaws, the particles settle vertically downward. With each freeze-thaw cycle, the particle is transported a millimeter or two downslope. The process tends to mix particles moving downslope from sources above, such as terrace gravels, with particles derived from the material that underlies the slope, such as the Potomac Formation, producing a massive, homogeneous-looking sediment that sometimes exhibits a crude, slope-parallel stratification. Some colluvial motion may also occur by soil creep, caused by internal deformation of the underlying soil under its own weight. Creep chiefly affects clay-rich soils and is most effective when soils are very wet, such as right after spring thaw and heavy rainstorms. Landslide deposits are another common kind of slope deposit in the map area, especially on the clayey slopes, and range from coherent, rotational slump blocks to liquefied debris flows. Debris fans, composed chiefly of sandy to loamy slope wash and colluvium are also abundant at the bases of some long, steep slopes.

The ages of the slope deposits are difficult to determine precisely, but appear to vary widely. Gravelly colluvium draped over knobs and slopes in the highest parts of the landscape commonly exhibits strong weathering profiles and may be nearly as old as the upland terraces, while colluvial fans along the margins of deeply entrenched young valleys are clearly much younger. Some large complexes, and many smaller bodies, of slope deposits have probably experienced prolonged periods of motion; they may have originated as far back as the late Tertiary but have continued accumulating through the Pleistocene and Holocene. Likewise, the scars left by prehistoric landslides may persist for thousands of years. The slope deposits are divided into five main categories on plate

5, according to their physical properties, mode of origin, position in the landscape, and apparent age.

Colluvium of Pleistocene to Recent age is found on virtually every slope in the map area. It typically forms fan-shaped bodies at the bases of slopes, as well as aprons, sheets, and linear "chutes" that fill small rills and hollows. Colluvium typically consists of well-rounded pebbles, cobbles, and some boulders of quartz-rich lithologies identical to those found in the upland terraces. These coarse fragments are set in a stiff to hard matrix composed of variable proportions of sand, silt, and clay. Although some of these finer particles are also derived from the same upland gravels as the coarse clasts, the composition of the matrix on any particular slope also tends to be influenced by the texture of the underlying sediment: colluvium that moves downslope over clayey Potomac Formation sediment, for example, tends to have a heavier matrix than colluvium that overlies sandy sediment. Thickness of the colluvium also is spatially variable, and is greatly influenced by slope shape: the thickest deposits are found in hollows, ravines, toeslopes, and other concave slope positions, while the colluvium is much thinner, and frequently discontinuous, on convex parts of the landscape. Observed thicknesses of mapped bodies are commonly in the range of 3 to 6 feet, but colluvium approaching, or even exceeding, 15 feet thick was observed in several favorable exposures along toeslopes. Most bodies of colluvium are relatively well drained and are reasonably stable; however, bodies that overlie clayey Potomac Formation sediments at shallow depth on steep slopes, or that have entrained significant quantities of expandable clay from the underlying material, may become unstable and susceptible to landslides if disturbed. Instability is particularly likely to result from the removal of the toes of bodies through "cut and fill" operations: doing so reduces the lateral strength of the material. Colluvium occurs at many positions in the landscape and probably ranges considerably in age. Some bodies show a moderately well developed soil profile with appreciable clay pickup in the subsoil, suggesting they are at least as old as late Pleistocene, whereas others show only incipient soil horizonation, indicating they have accumulated relatively recently. No particular pattern was observed between the degree of soil development and position in the landscape of this unit (as distinct from "high-level colluvium", see below).

High-level colluvium is distinguished from the previous unit chiefly by its much higher position in the landscape and by stronger soil development in many cases. It forms sheets, fans, and lag gravel along the edges of the four large upland terraces and in the heads of high-level ravines. It is very common along escarpments separating these terraces and is deeply weathered, typically forming the upper part of deep, brightly colored ultisols that extend down into the underlying Potomac Formation. This unit consists chiefly of iron-stained pebbles and cobbles identical to those found in the upland terraces. The pebbles are embedded in a stiff to very hard, fine- to medium-grained matrix composed of variable proportions of sand, silt, and clay. As with the previous unit, the particular composition of the matrix on any given hillside tends to reflect the texture of the underlying sediment, but the relationship is somewhat less pronounced because of the stronger soil development and attendant clay pickup. The greatest thickness observed in outcrop is about 10 feet, in the head of a ravine below Dowden terrace in Chambliss Park, but the unit may locally be as much as 20 feet thick based on some geotechnical borings. Most bodies of high-level colluvium are relatively well drained and stable, but some instability is possible where the colluvium overlies clayey Potomac Formation sediments at shallow depth on or adjacent to steep slopes—a very common setting of this unit since it tends to occur along the eroding edges of the upland terraces, above major ravines and drainages. The age spectrum of this unit is broadly comparable to that of the upland terraces: colluviation is believed to have occurred mainly in the late Tertiary and early Pleistocene, though some movement clearly continues today on some of the mapped bodies. A few bodies of colluvium mapped on nearly level, high-elevation spur ridges and summits may simply be lag gravel left over from the weathering of the adjacent upland terrace; in such cases, the material has moved little, if at all, from where it originated.

Loamy colluvium is somewhat similar to high-level colluvium in terms of landscape position, but is distinctly different in composition. Exposures of this unit are poor and tend to be restricted to scattered tree throws and low banks along gullies and rills. It forms gently-sloping aprons outboard of the toes of some of the escarpments between the upland terraces, and is composed chiefly of heavy loam or silt loam. The material lacks any obvious stratification, is largely devoid of pebbles and cobbles, and tends to be poorly drained. The thickness of these bodies is unknown, but is probably less than ten feet. The only non-urbanized body that still preserves a reasonably natural landscape is located at the east end of Episcopal Seminary, adjacent to Quaker Lane. This body has a somewhat swampy landscape dominated by hydric tree species and a shallow water table. The soil profile is typically mottled or gleyed. This unit is similar to the silt cap on the adjacent Chinquapin Village terrace, into which it grades, but it is distinguished by its higher position in the landscape and a more strongly sloping surface. It typically occurs in a somewhat more distal position than high-level colluvium, though the two occur in a mosaic at places at the seminary, with the loamy colluvium occupying the lower ground around a pebbly colluvial fan. The origin and age of this unit are enigmatic, but the most likely explanation is that it accumulated gradually in fans, probably as slope wash derived from the adjacent escarpments. A complete soil profile has not been observed, with the deepest exposure being about three feet below grade. The subsoil there, and at other places, exhibits moderate clay pickup, but is predominantly hydric, with gleyed colors. Small ephemeral rivulets debouch over the surface of the unit at the seminary, suggesting that deposition is still occurring. Therefore, this unit is inferred to be Pleistocene to Recent in age.

Debris fans are similar to colluvial fans, but they are more varied in composition and occupy the toeslopes where long, steep slopes on the Potomac Formation abut the inboard edges of relatively young terraces that border the large streams, such as the Old Town terrace. Exposures of this unit were observed in a few shallow trenches and excavations, and it was also described in several borings, where the maximum apparent thickness is less than ten feet. The fans consist mainly of loamy sand and pebbles, and are not as gravelly as colluvium. This presumably reflects a greater distance from the eroding edges of upland terraces, and a correspondingly larger contribution to sediment load from the Potomac Formation on the hillsides above. Some of the larger fans are localized in front of the mouths of ephemeral ravines, suggesting that running water contributed to sediment transport onto the fan surfaces. The loamy sand is interbedded with zones of coarse gravel on some terraces; these zones may be alluvium, which suggests that the fans began accumulating when streams occupied the terraces. If this is the case, the lower portions of these fans could be Sangamon age. It is unlikely they are any older, since the valleys they occupy were downcut to their present levels no earlier than the Sangamon, and in some cases, later. Some of the fans extend out for hundreds of feet over the sloping fronts of terraces and onto the edge of the modern floodplain. This is especially evident along Four Mile Run, and suggests that the fans are still active.

One of the more intriguing landscapes is the prominent embayment in the valley wall on the north side of Holmes Run, which extends downstream for a distance of almost two miles between Shirley Highway and Fort Williams Park. The undulating surface of the embayment slopes some 100 feet down to Holmes Run from the base of the massive “Hospital” escarpment bounding the south side of Seminary Terrace; the relatively smooth slope of this landscape is interrupted by several hills and small irregular ridges, as well as several perfectly level internal surfaces and small bluffs. Previous workers (e.g., Johnston, 1964; Drake and others, 1979; Froelich, 1985) have variously mapped this landscape as Potomac Formation, colluvium, Quaternary stream terraces, or some combination. In fact, it is all of these things and more, commingled in a complex mosaic that might best be described as a large **debris fan complex** derived from the collapse and retreat of the adjacent escarpment over a very long period of geologic time. This feature occupies an area larger than some of the upland terrace remnants, and is informally called the “**Seminary Valley debris fan complex**”, or Seminary Valley fan for short.

At various places, the surface of this landscape consists of alluvium, colluvium, slope wash, mudflows and other landslide debris, and alluvial fans, as well as sandy sediment of the Potomac Formation. The greatest variability occurs near the top of the fan, where an assortment of materials freshly debouched off the oversteepened slopes of the escarpment has collected. Numerous landslide scars and rotated slump blocks dot the escarpment (one large modern slide was observed during the fieldwork for this study), suggesting that slope failures have played an important role in the retreat of the bluff and in generating a steady supply of debris. Several steep, high-level ravines also terminate in small alluvial fans at the base of the escarpment, and provide another source of debris. The escarpment is capped by coarse cobble gravel of the Seminary terrace, which is being undermined at many places by small, unstable scarps developed on Arell clay. This process generates abundant colluvium, which accumulates along the toe of the scarp and is gradually transported outwards across the surface of the fan. Collectively, these varied processes result in a texturally heterogeneous assemblage of sediment near the summit of the debris fan. Further downslope, however, much of the debris has been reworked and homegenized by colluvial and alluvial processes as it has migrated down the surface of the fan, producing a relatively uniform sheet of sandy to loamy material. The thickness of the debris appears to be highly variable: borings near the summit of the fan suggest it may exceed 25 feet, whereas further down-fan, visual observation of small excavations and soil exposures indicates it ranges from a few inches to a few feet thick.

For purposes of mapping, the Seminary Valley fan is divided into two parts, upper and lower, which appear to have somewhat different histories. The larger, upper part of the fan is inferred to overlie a moderately hilly erosion surface developed mostly on the Cameron Valley sand member of the Potomac Formation, which pokes up through the surface of the fan at places, forming the prominent isolated hills and ridges. Soil exposures in these places invariably have a fine-sandy texture and typically lack the pebbles and cobbles that would be expected if these small hills were composed of colluvium or remnants of alluvial terraces. Such protuberances of the Potomac Formation are sparse in the western two thirds of the fan, but become increasingly pervasive by the time the far eastern end is reached. This relation offers important insights into the paleohydrology and possible origin of the fan: it seems likely that several ravines that currently debouch from the escarpment above the western part of the fan were once part of an integrated drainage that flowed southward towards Holmes Run. The smaller streams emanating from the ravines probably converged into one stream in the area where the western part of the fan now is, thereby eroding out a relatively broad basin in the sandy Potomac Formation sediments. At some point, influx of debris from the retreating escarpment simply overwhelmed the capacity of the streams to remove it, resulting in relatively rapid inflation of the fan surface. Once this tipping point was reached, the flow that issued from the ravines simply disappeared into the relatively permeable fan sediment as ground-water recharge, much as it does today, which is why the fan surface seems to lack any integrated drainage. A large volume of ground water derived from the fan now emerges in many large seeps and springs close to Holmes Run.

The smaller, lower part of the fan complex is characterized by several prominent level surfaces, or benches, at different elevations. These are alluvial terraces deposited by Holmes Run during the mid(?) to late Pleistocene, as it cut down in response to changing base level. At some places, the distal parts of the debris fan have clearly migrated over parts of these terraces, but at others, the fan surface is quite gravelly, reflecting reworking by running water and deposition of stream alluvium by Holmes Run. One could reasonably conclude that the fan was particularly active during the late Pleistocene, perhaps as a result of increased amounts of debris being generated by a wet Ice Age climate.

The age of the Seminary Valley fan depends to an extent on the ages of the upland terraces, and particularly the adjacent Seminary terrace, whose retreat has furnished most of the debris that makes up the fan. It is not known how long an escarpment has existed at this location. Theoretically, one could have formed shortly after deposition of the Seminary terrace, when the river cut down to the level of the Chinquapin Village terrace, but any evidence was stripped away when Holmes Run Valley was cut. The head of the fan is typically at an elevation of around 150 feet, the same as the Beverley Hills terrace. The present form of the fan could not have been established until local streams, including Holmes Run, cut down below this level. Thus, the inception of the fan post dates the Beverley Hills terrace. Retreat of the escarpment probably accelerated greatly with the onset of the Pleistocene and rapid downcutting of the Holmes Run Valley. A wetter Ice Age climate may have also helped to oversteepen the slope of the escarpment and trigger slope failures, increasing sediment volume. At the other end of the fan, the toe appears to terminate on an eroded terrace, remnants of which can be traced almost continuously down Holmes and Cameron Runs into the Old Town terrace, which is interpreted to be of

Sangamon (late Pleistocene) age. There is no evidence that the fan extends out over any lower terraces or the modern floodplain. Based on these relations, the fan was clearly being deposited during and after the Old Town terrace formed, but deposition appears to have ceased by the time the lower terraces (presumably Holocene) had formed. Taken together, the weight of the evidence suggests that most of the Seminary Valley fan formed between the mid Pleistocene and the early Holocene. The surface of the fan is not static, however, and the same kinds of processes that operated in the Pleistocene continue to operate today, though presumably at a significantly slower rate. This is especially true of the upper part of the fan, which continues to receive landslide debris and colluvium shed from the escarpment.

Pleistocene-Recent Stream Deposits: Alluvial deposits occur in a variety of landscape positions, ranging in elevation from just below the upland terraces to the floodplains of modern streams. Their distribution records the periodic incision of the major valleys during the Pleistocene: during periods of maximum ice cover, sea levels were depressed by as much as 300 feet or more, causing local streams to vigorously incise their valleys. In contrast, during prolonged warm interglacial periods sea level returned to levels comparable to today's; streams eventually stabilized during these periods and deposited terraces. This cycle repeated numerous times during the million years of the Pleistocene. The best known glaciation is the most recent—the Wisconsin Stage—which lasted from roughly 70,000 to 10,000 ybp. Ice did not invade the northern US, however, until the late Wisconsin, about 25,000 ybp, but there is evidence of continental ice sheets elsewhere in the world earlier in the Wisconsin stage. The Sangamon Interglacial lasted from the end of the Illinoian glaciation, some 140,000 ybp, to the beginning of the Wisconsin, and was marked by a warm, wet climate that enhanced weathering and stream loads. It is not surprising that a terrace as massive as the Old Town formed during the Sangamon. The Illinoian glaciation lasted from roughly 350,000 to 140,000 ybp, and is known to have had at least three major substages in its type area in Illinois and Indiana, punctuated by two long, warm, interstadials when the ice sheets receded and major soil formation occurred.

Interpretation of pre-Illinoian glacial and interglacial history gets more complicated as the evidence gets farther away. At one time, the Pleistocene was divided into four stages: the Wisconsin, Illinoian, Kansan, and Nebraskan, based on the inferred ages of Midwestern "drift" sheets separated by major weathering profiles. This simplistic model has largely been discarded, as stratigraphic evidence from deep buried bedrock valleys and data from Greenland ice cores have emerged to reveal a far more complicated picture. In Indiana, for example, the oldest glacigenic deposit in the bottom of the Teays Valley, known as the "West Lebanon sequence", is magnetically reversed, putting its age somewhere around 750,000-900,000 years. Several sequences in turn overlie the West Lebanon, before the classic Illinoian section is reached higher in the valley fill. If all of the glacial stages represented by even this one local example were separated by warm interglacials and interstadials, then there should be evidence in the form of some 6 or 8 sets of major Pleistocene terraces in the Potomac River basin. So far, geologists have not found them—that is, assuming none of the upland terraces described earlier are Pleistocene. Four presumed Pleistocene terraces are mapped in Washington D.C.

(Fleming and others, 1994), but the oldest of these is inferred to be no older than 450,000 years, which would roughly place it as the product of the Yarmouth Interglacial, a period thought to have been even longer and warmer than the Sangamon, and which immediately preceding the Illinoian glaciation. This leaves a lot of the Pleistocene unaccounted for in the local record. In Alexandria, there is an even more glaring gap in the record, at least as the terraces are currently interpreted, between the Old Town terrace and the Beverley Hills terrace. If the latter is assumed to be late Tertiary, then virtually the entire Pleistocene is omitted from the terrace record in the city. Clearly, our current understanding of the terraces leaves many unanswered questions!

Several kinds of alluvial deposits are mapped on plate 5 based on their composition and position in the landscape relative to other landforms. The bottoms of the major valleys contain an array of younger terraces and other deposits associated with the modern streams. Coarse sand and gravel is a predominant component of most of these, but fine-grained sediments are also important at places, for example, in swamp deposits and overbank deposits that cap terraces. By virtue of their positions in the landscape, the ages of most of these can be better constrained than the upland terraces, but are still somewhat speculative, given the absence of hard radiometric dates or index fossils from within the city. Most of the lowland sediments, for example, are Holocene in age, but some terraces and alluvial fans are clearly older.

High-level terrace remnants consist of isolated, gravelly patches and small terrace-like landforms found at widely divergent elevations and positions along the valley walls of most of the major drainages, especially Cameron and Holmes Runs. Although a few of these still preserve a relatively convincing, level terrace surface, most are small scraps of moderately sloping gravel that have been severely eroded, and some may simply represent a gravel lag or colluvium. They occur at higher landscape positions than the Old Town terrace, and are thus older. Most are at lower elevations than the Beverley Hills terrace, but some units mapped on the sides of Holmes Run Valley are higher. Some of these deposits could easily date back to the early or mid Pleistocene. Assigning an age is highly problematic, however, not only for the reasons elucidated previously, but also because, unlike the upland or Old Town terraces, they are widely scattered and do not form readily identifiable terrace straths. The details of these bodies are poorly known. There are almost no geotechnical borings located on any of these bodies, and information is derived largely from a few small surface exposures and from their geomorphic expression. All of these bodies consist of strongly weathered gravel and sand, most of which appears to have been reworked from the upland terraces. Brightly colored ultisols are typical. Based on the map pattern, the apparent thickness of most is less than 10 feet, though the largest ones could be thicker. Functionally, these bodies act much like gently-sloping colluvium in the landscape: they are well drained and promote ground-water recharge, and they tend to create dry, strongly acidic soil environments.

The **Old Town terrace** is the single largest landform in the city, and it occupies an area larger than any other map unit—larger, in fact, than *all* the other upland and lowland river terraces combined. It underlies virtually all of Del Ray and Old Town, where it forms a weakly dissected plain whose surface elevation is most commonly in the range of

35 to 50 feet. A set of terraces that is clearly graded to the main Old Town terrace can be traced almost continuously for several miles up the valley of Cameron Run, and is shown on plate 5. Somewhat less extensive terraces in the lowermost part of Four Mile Run Valley are also thought to correlate with the Old Town terrace, based on their comparable strath levels. A set of narrow, but prominent terraces that flank Timber Branch also are graded to the main Old Town terrace and are thus interpreted to be part of that terrace system.

The geology of the Old Town terrace is relatively well known, because it is penetrated by hundreds of geotechnical borings and old water wells from the mouth of Cameron Run northward to Glebe Road and Four Mile Run, and because it crops out frequently in stream cuts in the Cameron and Backlick Valleys. Large parts of the section consist of coarse sandy gravel; thick cobble and boulder gravels, for example, crop out in cuts along Holmes and Backlick Runs. Beneath Old Town, the thickness of the terrace is almost everywhere greater than 50 feet, and it approaches 125 feet over what is inferred to be the thalweg of the ancient Potomac River, roughly coincident with the modern waterfront. In numerous wells and test borings, the terrace is defined by a broadly upward-fining sedimentary sequence. The lower half or so of the sequence consists chiefly of interbedded gravel and sand, which grades up through interbedded pebbly sand and muddy sand into interbedded mud and fine sand that dominate the top of the terrace. Subsurface and geomorphic data suggest that most of the terrace surface in Del Ray, and nearly all of it above 30-35 feet elevation, is composed mainly of silt and clay with minor interbedded sands, whereas parts of the terrace surface below 30-35 feet are mainly composed of muddy sand. The surface of the terrace has been extensively modified by 400 years of urbanization, consequently fill and disturbed ground are ubiquitous. The age of the terrace is widely regarded to be Sangamon; Drake and others (1979) speculated that it might be early to middle Sangamon, which is a reasonable conclusion, considering that the most rapid alluviation probably followed closely the sea level rise at the close of Illinoian glaciation and subsequent infilling of the drowned river valley that was carved during the Illinoian maximum. Nevertheless, there is no reason to think that deposition of the upper, finer-grained parts of the terrace could not have extended into late Sangamon time. The Old Town terrace is thought to be correlative with a similar terrace that underlies parts of the mall and adjacent places in Washington, D.C., and which has been correlated with fossiliferous units on the Coastal Plain about 70,000 years old (late Sangamon). This age probably reflects the timing of the deposition of the uppermost parts of the terrace.

Alluvial fans were mapped in the mouths of several ravines, where they debouch onto relatively level terraces and floodplains. Most of the fans are heavily urbanized; a few geotechnical borings and small surface exposures indicate that the composition of the fans is varied, but consists mainly of coarser sediment fractions, mainly gravelly sand and loamy-textured alluvium. These sediments occur in classic, fan-shaped landforms that emanate from the mouths of steep-sided ravines. The thickness of the alluvial fan near Van Dorn Street and Edsall Road appears to range from 5 to 20 feet in geotechnical borings; the thicknesses of the other fans shown on the map are not well known but are probably similar. The morphologies of the fan surfaces and their relationships to the lowlands they debouch into suggest the fans are of different ages. Some fan surfaces slope smoothly into the lowlands; most of these grade into Holocene alluvium and stream terraces, indicating they are relatively young features whose deposition has been ongoing since the terraces were deposited. The large fans on the north side of Four Mile Run near Arlandria are good examples. Other fans are graded to remnants of the Old Town terrace, suggesting they may be late Wisconsin or older. The fans in the southwestern part of the city are of this type. Still others have steep fronts that appear to have been incised by modern streams, suggesting they are not in equilibrium with the elevations of modern valley bottoms, and may be significantly older. The fan on the south side of Four Mile Run at Shirley Highway is one example.

A variety of younger **stream terraces** is found in all of the major valleys. The terraces typically border the modern channels of the streams and their surfaces mostly stand less than 10-15 feet above the base flow stage of the streams. In most drainages, these terraces broadly correspond to the modern floodplain, and are periodically inundated by floods at intervals ranging from every year or two to perhaps as long as 100 years. In exceptional cases, the terrace surfaces may stand as much as 15-20 feet above modern streams, but this is usually the case where there are multiple sets of terraces along a drainage. This situation is found mainly along lower Cameron Run and the Potomac River. Exposures and borehole data suggest that the terraces are composed principally of coarse cobble gravel below, and grade up into finer sands and muds near their surfaces. The higher and more distal portions of the terraces tend to have more fine-grained sediment in the section, especially close to the terrace surfaces. At some places, there are multiple fining-upwards sequences in the terraces, or complex cut-and-fill relations produced by erosion and deposition during different flood events. The thickness of the alluvium ranges up to 25 feet, but is mostly much less. All of these terraces are lower than the Old Town terrace, hence they are inferred to range from latest Wisconsin to Holocene in age, with most being the latter.

Recent swamp deposits consist chiefly of organic-rich silt and clay deposited in broad, slack swales and in backwaters along the major drainages. Good exposures of swamp deposits occur for several hundred feet along an unnamed tributary of Cameron Run in Tarleton Park, between Wheeler and Vermont Streets. Most of these deposits consist of clayey silt. A faint slabbiness or fissility, along with layers of organics that presumably represent soil horizons, are the only suggestions of stratification; otherwise the deposits appear fairly massive. Although the thickness of these deposits is not well known, it is probably not great, perhaps 5 feet or less, in most places, because the unit typically occupies relatively shallow swales. On the other hand, it could be substantial in some of the larger backwater swamps along Four Mile and Cameron Runs.

The swamp deposits are closely associated with both the Old Town terrace and younger terraces. Extensive areas of these deposits occupy swales on the main part of the Old Town terrace and result in a very poorly drained landscape that still exhibits a fair number of relict swamp trees, such as pin oak, sweet gum, and silver maple. Soils formed in these deposits are gleyed entisols with limited horizonation and very poor permeability. The water table typically lies within inches of the surface in undrained areas. Some of these deposits occur in small to medium-sized backwaters between the terraces along drainages. Good examples occur along the lowermost reaches of Four Mile Run, as well as the aforementioned site in Tarleton Park. In some of these places, the mouths of these backwaters are dammed by alluvium, either natural levees or small terraces, or may have been in the past, producing the backwater swamps. The map very probably underrepresents the abundance of these swamp deposits in the landscape: extensive parts of Cameron, Holmes, and Four Mile Run Valleys have been filled or otherwise altered by stream channelization and other "improvements". Most of the filled area appears to have consisted of swamps, judging by a comparison to old topographic and historical maps of the area.

Recent alluvium occurs in the floodways of most streams, and consists of laterally and vertically variable deposits of boulders, gravel, sand, and mud. In the larger streams, the sand-sized fraction commonly contains abundant mica derived from weathered bedrock higher in these watersheds. This map unit also includes a few very low-lying stream terraces of probable Recent age, chiefly adjacent to the Potomac River along the Old Town waterfront. The thickness of the alluvium ranges widely and is greatest along the master drainages, and much less in the smaller ravines. The largest thickness observed in outcrop is about 10 feet, along Cameron Run, but the bottom of the unit was not exposed there. In the records of wells and geotechnical borings, it is often difficult to differentiate recent alluvium from older alluvium in terraces; the two are often closely associated, for example, the channels of many modern streams are often cut into older alluvial terraces, with the channel being floored by older deposits.

A variety of fluvial features are associated with alluvial bottomlands, the most common being point bars, natural levees, and small sloughs and oxbows, which often occur together. These are indicated on the map where they are particularly prominent or of high quality from an ecological standpoint. The best example of a high-quality natural levee and oxbow system within the city limits occurs on the north side of Holmes Run just downstream of North Chambliss Street. This system is developed on a large point bar and is virtually pristine. It experiences regular natural disturbances from high-energy floods, leading to a variety of unique ecological habitats concentrated in a small area. There is no other area like it in the city that I am aware of. Similar places were undoubtedly common at one time along many of the larger drainages, but nearly all of these streams are severely altered by urbanization, channelization, and excessive storm-water inputs.

At places along all of the major drainages, as well as in many of the smaller ones, the modern streams flow in artificial channels created in the name of "flood control" or to make way for urban development. These artificial channels seldom follow the original, pre-settlement courses of the streams, and sometimes deviate dramatically from them. This is particularly true of Cameron Run, which has been radically altered by filling and channelization. In most parts of this valley, therefore, the distribution of map units, such as Recent alluvium and some stream terraces, in no way corresponds to the present location of the stream. The original location of Cameron Run was determined from a combination of historical maps (some available in the city library, and others in Stephenson, 1981) and geomorphology, and is indicated on the map.

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